APPENDIX H
THE APPLICATION OF THE ST. LUCIE ESTUARY HYDRODYNAMICS/SALINITY MODEL IN THE INDIAN RIVER LAGOON AND ST. LUCIE ESTUARY ENVIRONMENTAL STUDY

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AREA OF MODEL COVERAGE AND DATA COLLECTION SITES

The St. Lucie Estuary hydrodynamics/salinity model covers the entire St. Lucie Estuary and a portion of Indian River Lagoon (**Figure H-1**). The model domain includes the North and South Forks of the St. Lucie River, the middle and lower St. Lucie Estuary, the St. Lucie Inlet, and the Indian River Lagoon between Nettles Island and Pecks Lake.

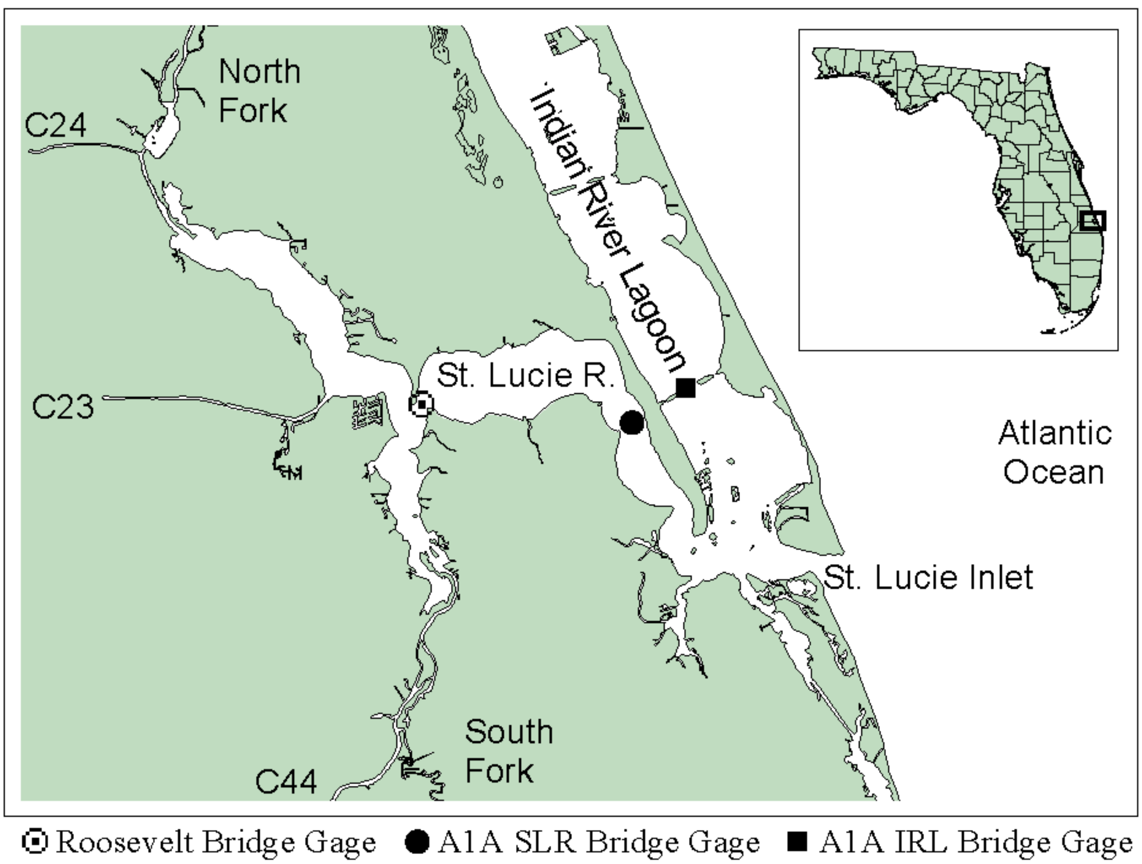

Figure H-1. Model Domain and Locations of Tide/Salinity Data Collection Stations

Tide/salinity stations were installed in the St. Lucie Estuary in early 1997. The locations of three stations are shown in **Figure H-1**. Since August 1997, these stations have recorded more then three years' worth of data. Tide (water surface elevation), currents (flow velocity), salinity, and temperature are recorded continuously at 15 minutes intervals. Salinity and temperature are measured at two different depths to detect stratification in the water column. The data can be retrieved through satellite with approximately four hours lag time. After the model verification was completed in early 1999, the stations have mainly served as monitoring stations. The near real time data provided first hand information for environmental assessment and operational planning. The data collection program was extended in January 1999 when five more tide/salinity stations were installed in the Indian River Lagoon between the Fort Pierce Inlet and Pecks Lake.

MODEL DESCRIPTION

The St. Lucie Estuary hydrodynamics/salinity model is a two-dimensional finite element model (Hu, 1999). The model was developed to assess the impact of drainage canal discharge and storm water runoff. The model also provides hydraulic information for water quality study and modeling. **Figure H-2** is the finite element mesh of the model. Both triangular and quadrilateral elements are used in the mesh to fit the complex shoreline. In order to establish a more stable salinity boundary condition (Hu and Unsell, 1998), the model mesh was extended approximately 6 miles off shore into the Atlantic Ocean. The model geometry is based on a bathymetric survey conducted in 1998. Portions of major drainage canals were included in the model mesh using single line of quadrilateral elements.

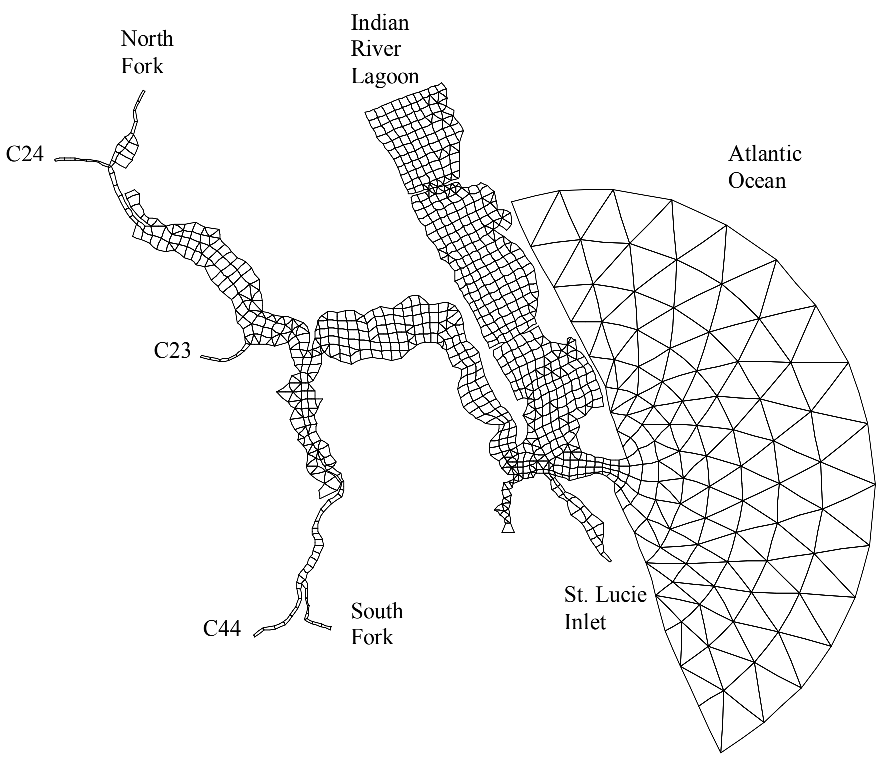

Figure H-2. Finite Element Mesh of the St. Lucie Estuary Model

The model computes tides (water surface elevation), two-dimensional velocity field, and salinity distribution in the model domain. The United States Army Corps of Engineers' RMA 2 model was used for hydrodynamics and RMA 4 was used for salinity simulation. Since the main interest of this study is in the impact of watershed runoff on the overall salinity regime in the estuary, a two-dimensional depth averaged approach was considered sufficient. For water quality study at the next stage, the model will be converted to a three-dimensional version.

MODEL VERIFICATION

Tidal boundary conditions were generated using a tidal constituent database developed by the Waterways Experiment Station of the United States Army Corps of Engineers. Canal and tributary discharges were based on field measurements and a watershed runoff model, the Hydrologic Simulation Program - FORTRAN (HSPF).

The model was first tested against National Ocean Service tidal data. Mean tidal range of the model output was compared with National Ocean Service data and had a margin of error less than 5 percent.

The model was further applied to the 1997 to 1998 ENSO episode. Tidal data and salinity data collected from November 1997 through June 1998 were used in model sensitivity analysis and verification. **Figures H-3** and **H-4** compare model output with field data. The field measurements were taken at two different depths to reflect any possible stratification. For most of the model testing period, the salinity records showed a clear salinity stratification with a low-salinity layer (fresh water) at the surface. The model output is depth-averaged salinity. Therefore, it falls between the two field measurements.

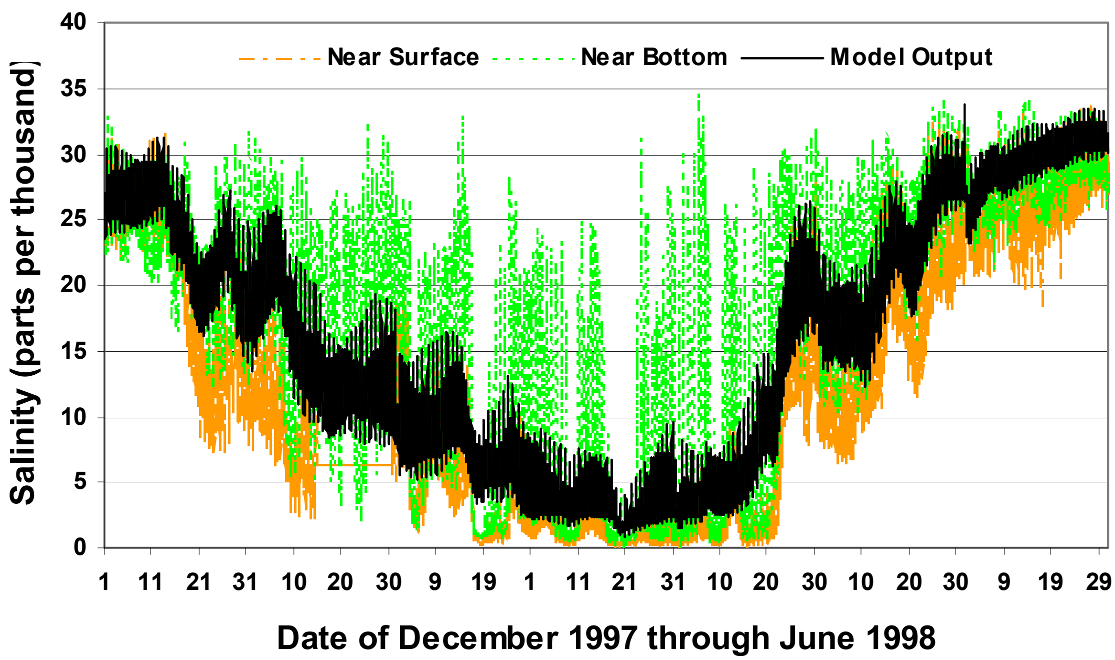

Figure H-3. Model Verification at the A1A Bridge Station in the Lower Estuary

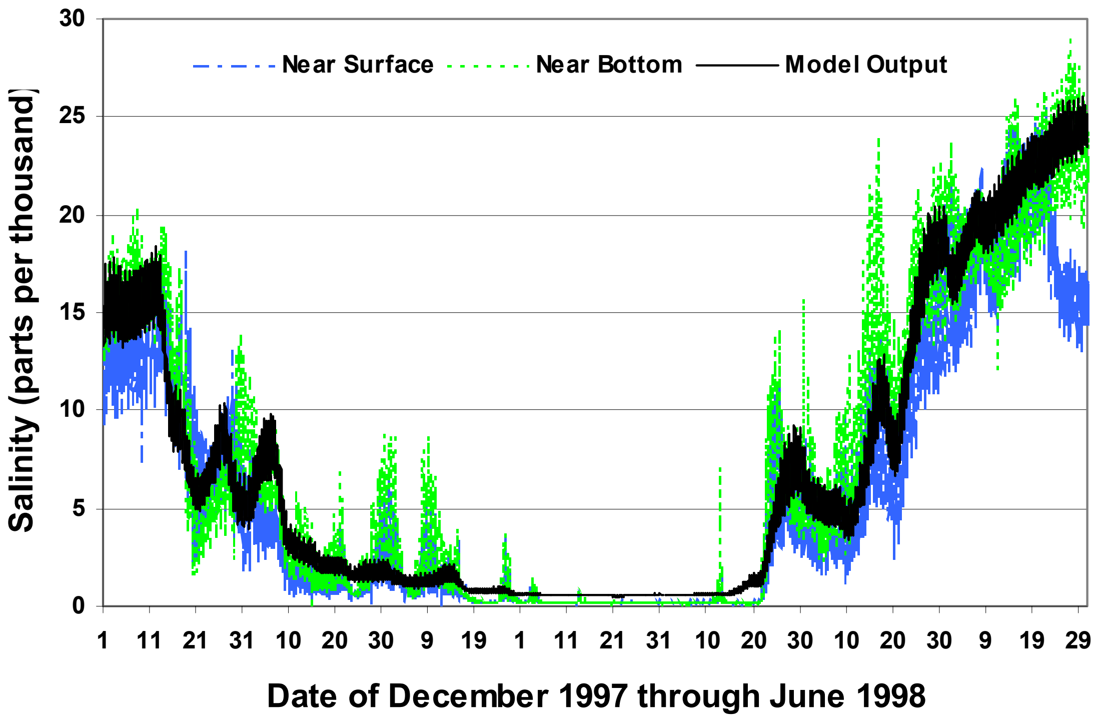

Figure H-4. Model Verification at the Roosevelt Bridge Station in the Upper Estuary

IMPACT OF CANAL DISCHARGE ON THE ESTUARINE SALINITY

Drainage canal discharge has a major impact on the salinity condition in the estuary. The estuary model was applied to various freshwater inflow conditions to establish a relationship between the magnitude of freshwater inflow and the estuarine salinity condition. Thirty-three model simulations were conducted with eleven different freshwater inflows at 300 cubic feet per second (cfs), 500 cfs, 700 cfs, 1,000 cfs, 1,300 cfs, 1,600 cfs, 2,000 cfs, 2,500 cfs, 3,000 cfs, 5,000 cfs, and 10,000 cfs. This covers the full range of freshwater inflow found in historic records. The freshwater inflow included both surface and subsurface (ground water) input to the estuary. Ocean tidal boundary condition for these simulations are monthly tides with two spring tides and two neap tides. The model output was used to create eleven salinity contour maps presenting the spatial distribution of salinity for each level of freshwater input. The color plate attached to this document is a mosaic of six salinity contour maps that show the trend of salinity declining when fresh water inflow increases.

The model simulations indicate that when total freshwater inflow reaches the 2,000 to 3,000-cfs level, the upper estuary will be dominated by fresh water and salinity in the area will main close to zero even during high tide. The extend of freshwater domination depends on the magnitude of freshwater inflow. If total inflow reaches 10,000 cfs, the zero salinity zone will extend to the A1A bridge and Hellgate in the lower estuary. Since the data collection program began in 1997, several major storm events and high regulatory releases have occurred. The salinity records obtained in these events confirmed that the model prediction of inflow/salinity relationship was accurate.

For quick reference, two salinity profile charts were created that describe the salinity gradients from the St. Lucie Inlet up to the South and North Forks (**Figures H-5** and **H-6**, respectively). Each line in **Figure H-5** represents the longitudinal salinity gradient from St. Lucie Inlet to the junction of the C-24 Canal and the North Fork. Each line in **Figure H-6** represents the longitudinal salinity gradient from the junction of the C-44 Canal to the old South Fork.

To find the salinity gradient for a freshwater discharge that falls between any two of the eleven flow levels, linear interpolation can be used. Since the salinity difference between any two lines in the chart is less than 5 parts per thousand (ppt). The error in interpolation should be less than 1 to 2 ppt.

The flow-salinity relationship charts were used to assist decision making in system restoration/operation planning. Given the magnitude of total freshwater inflow, the likely resulting salinity gradients/distribution in the estuary can be found in the charts and salinity contour maps.

The computations were based on the assumption of constant, uniformly distributed, runoff discharge. These charts were intended for quick, preliminary assessment purposes. If more detailed, accurate predictions are required, it is necessary to conduct dynamic model simulations with flow/tide boundary condition input.

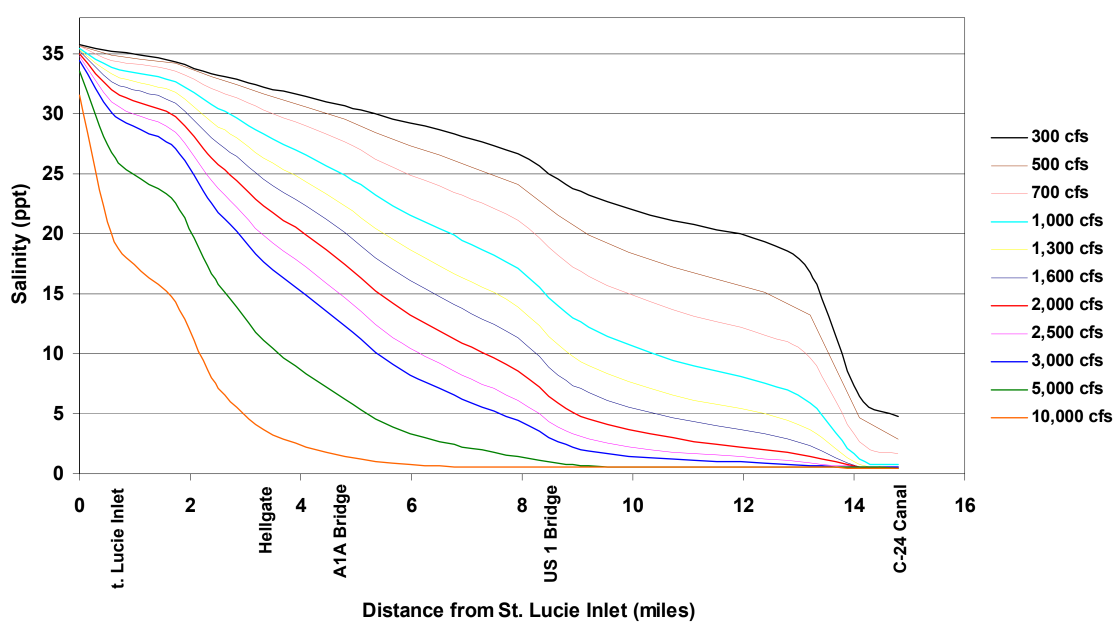

Figure H-5. Model Predicted Salinity Conditions at Various Magnitudes of Freshwater from St. Lucie Inlet to the North Fork

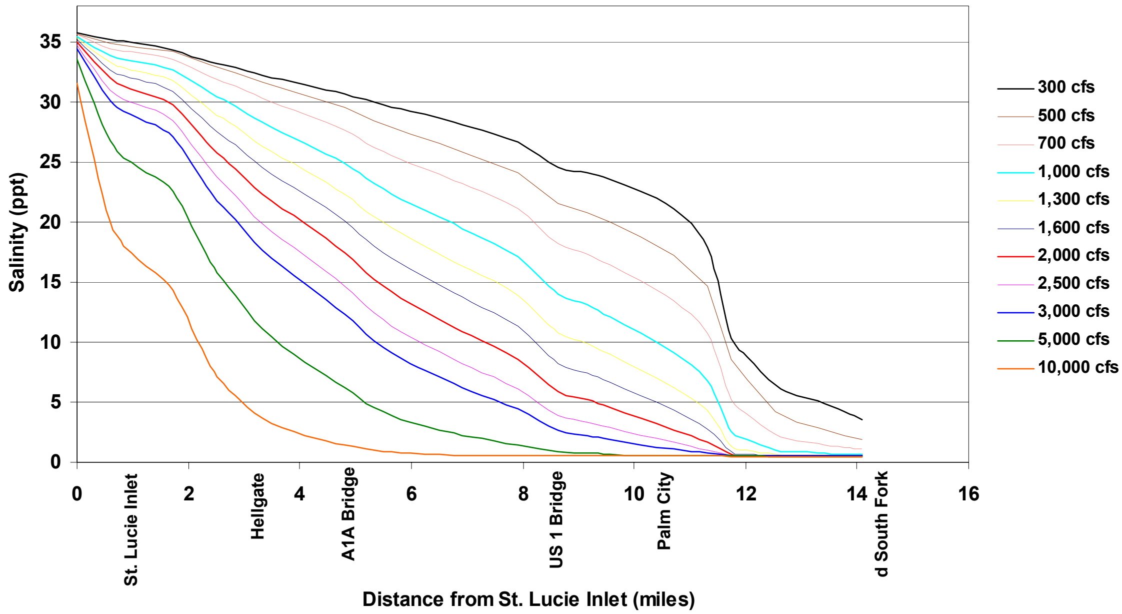

Figure H-6. Model Predicted Salinity Conditions at Various Magnitudes of Freshwater Inflow

LONG-TERM SALINITY COMPUTATION

A utility computer code was developed by SFWMD to facilitate the need for long-term salinity computations in alternative evaluations. Based on simulations using this code with various freshwater inflows, a flow-salinity relationship was established for several locations in the estuary. **Figure H-7** presents the flow-salinity relationship for Station SE03 located at the US 1 (Roosevelt) Bridge in the upper estuary. **Figure H-8** presents the flow-salinity relationship for Station 01 located at the A1A Bridge near Hellgate in the lower estuary.

While the salinity levels in the charts present the equilibrium state with steady freshwater inflow, in reality, freshwater inflow is rarely constant. The salinity condition observed in the estuary is the result of a series of transitions from one state to the next. Therefore, the change in salinity always lags behind the flow change. **Figure H-9** is an example of such a transition at Station SE03.

Data has been collected at the tide/salinity stations deployed in the estuary fore more than 3 years, beginning in August 1997. When canal discharge changes, the salinity changes occur accordingly. Based on the observation of several dozen such events in the past few years, it appears that a large portion of salinity transition occurs with in a week. It takes approximately two weeks for the transition to complete. This observation was consistent with the salinity model prediction.

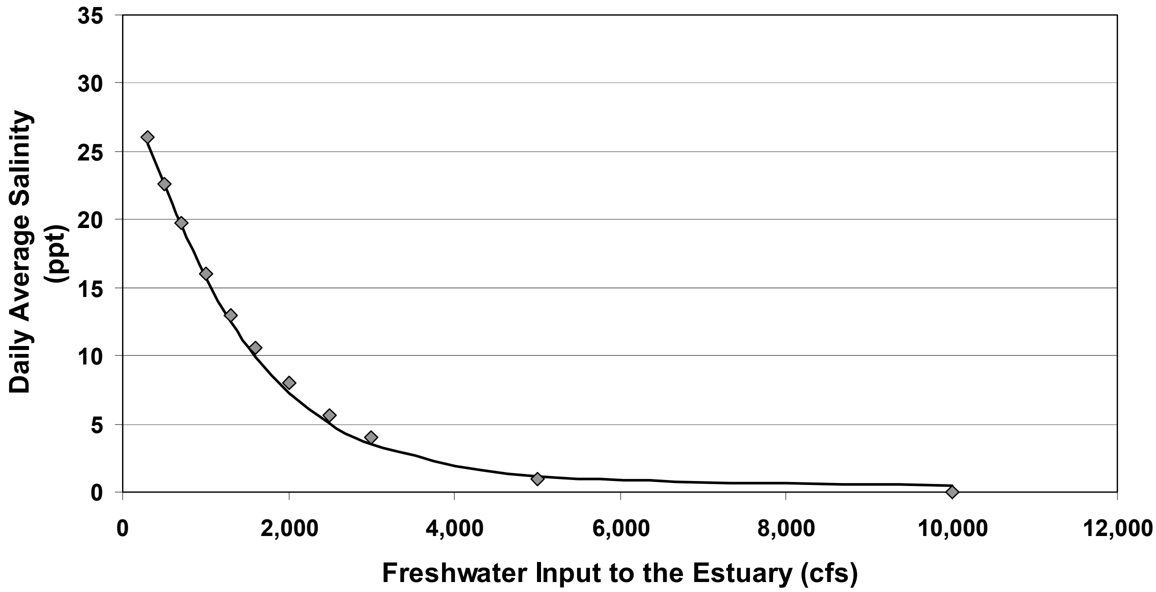

Figure H-7. Salinity - Flow Relationship at the US 1 (Roosevelt) Bridge in the Upper Estuary.

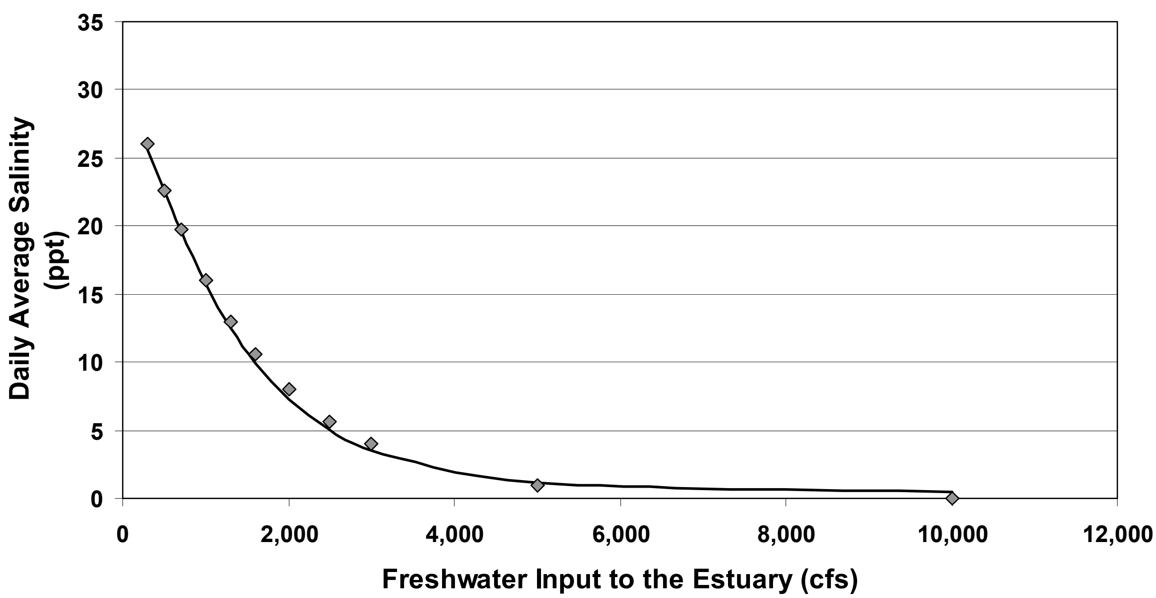

Figure H-8. Salinity - Flow Relationship at the A1A Bridge at Hellgate in the Lower Estuary

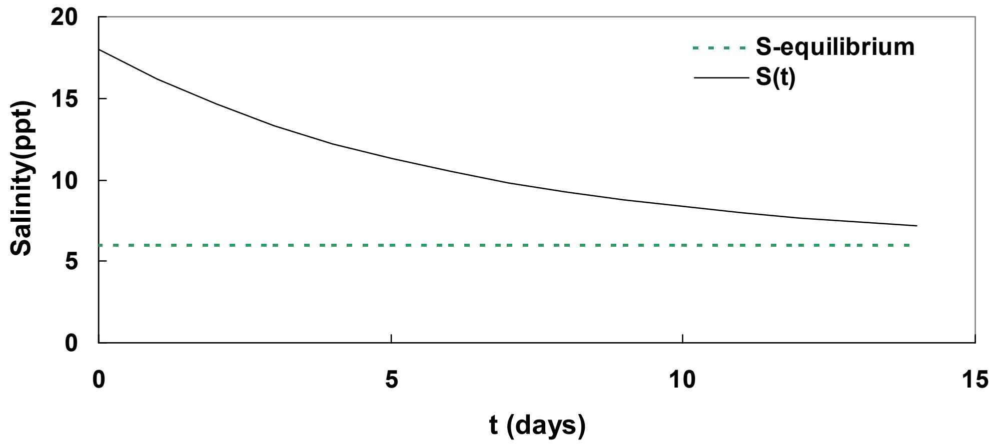

Figure H-9. Salinity Regime Transition Process at Station SE03

Both field observation and model simulation indicate that the salinity condition in the estuary consists of a series of transitions from one quasi-equilibrium condition to another. A utility computer code was developed based on this concept. Both field data and model output were analyzed to establish the transition time and freshwater inflow-salinity relationship for stations in the estuary. The computer program first calculates the potential target (equilibrium) salinity based on the magnitude of freshwater inflow. Then it calculates the salinity change on daily time steps. This calculation would consider both target salinity and the initial salinity condition. If further freshwater inflow change occurs before the transition is complete, then a new transition begins and the program repeats the same computational procedure for the new transition.

Figures H-10 and **H-11** are the testing output of the utility code. The output was compared with real data at two salinity stations in the estuary. Since the utility code operates on daily time steps, the model output is a daily-averaged value that does not depict the daily variation due to high and low tides. The testing case includes one of the highest regulatory releases ever made through the C-44 Canal. The salinity regime experienced extreme changes during that time period. The utility computer program performed well under these extreme events and the model output matched the field records closely.

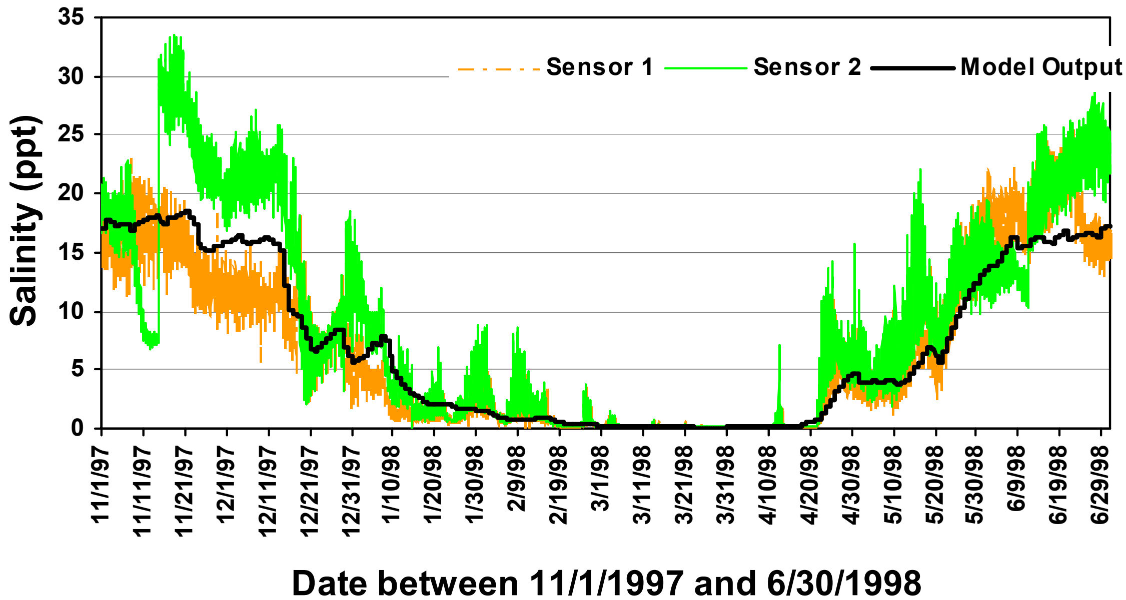

Figure H-10. Results of Long-Term Simulation Testing at the US 1 (Roosevelt) Bridge in the Upper Estuary.

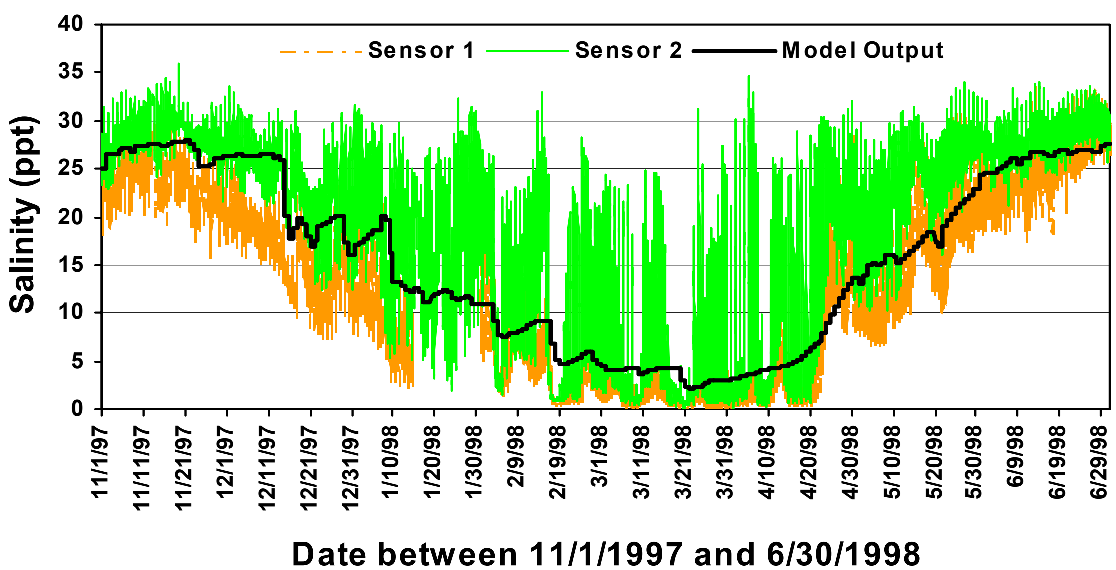

Figure H-11. Results of Long-Term Simulation Testing at the A1A Bridge in the Lower Estuary.

SALINITY COMPUTATIONS UNDER HISTORIC (NATURAL), PRESENT, AND "FUTURE WITH PROJECT" CONDITIONS

To evaluate plans for watershed management and drainage canal operations, salinity computations were conducted under the following four scenarios:

- Simulation 1 - 31-year period simulation under 1995 Base Case conditions
- Simulation 2 - 31-year period simulation with output from the Natural Systems Model (NSM) (**Figure H-12**)
- Simulation 3 - 31-year period simulation with assumed predevelopment land use (mostly forest and wetland)
- Simulation 4 - 31-year period simulation with a proposed watershed management plan (**Figure H-13**)

The purpose of Simulations 2 and 3 was to establish natural salinity conditions in the predevelopment era. Model output indicates that the salinity in the estuary was more stable under natural conditions in contrast to the present condition. The model output with the proposed watershed management plan predicted that the occurrence of extremely low salinity will be less frequent under "future with project" conditions.

Figures H-12 and **H-13** contain a huge amount of information drawn from simulations over a 31-year time series. The differences between scenarios would be difficult to read from such condensed charts. The intention of this memo is to provide an outline of the St. Lucie Estuary hydrodynamics/salinity model and its applications in Indian River Lagoon and St. Lucie Estuary study. More detailed analysis on the results of these simulations could be found in other reports of this project.

MODEL ASSUMPTIONS AND LIMITATIONS

The freshwater inflow in the salinity relationship includes both surface and subsurface (ground water) input to the system. When generating freshwater input for model simulations, both surface and subsurface hydrology should be included.

The model is two-dimensional depth averaged. Therefore, the model does not simulate the stratification in the water column. While depth averaged salinity is sufficient to describe the overall salinity regime on a macro scope, it does not reflect the salinity difference between the surface layer and the bottom layer when the system is stratified. For biological study, it is necessary to consider the factor of stratification. According to the current work plan, the model will be converted to a three-dimensional version in the near future.

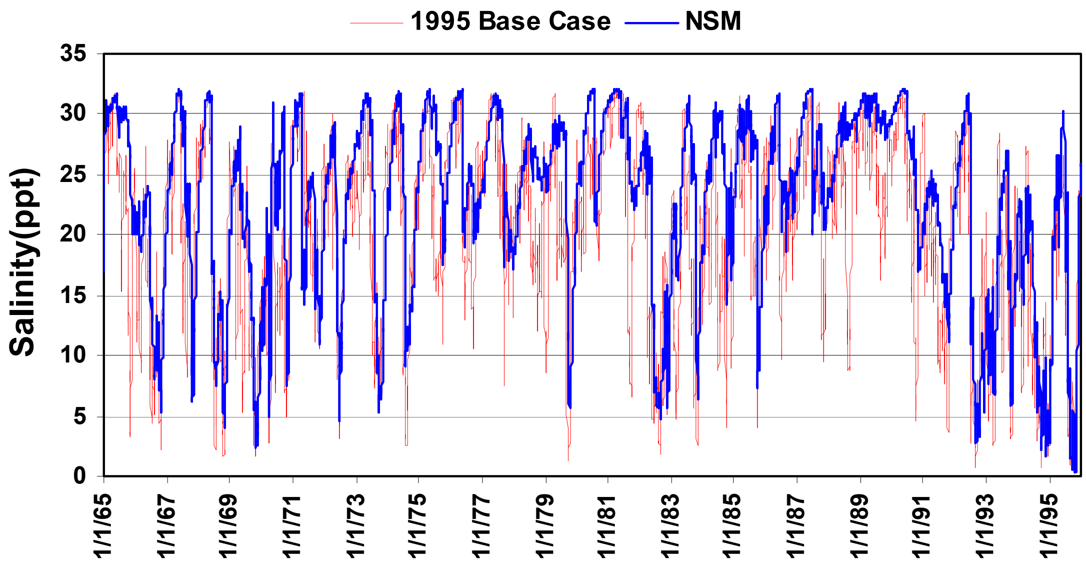

Figure H-12. Natural (NSM) versus Present (1995 Base Case) Conditions Salinity at US 1 (Roosevelt) Bridge

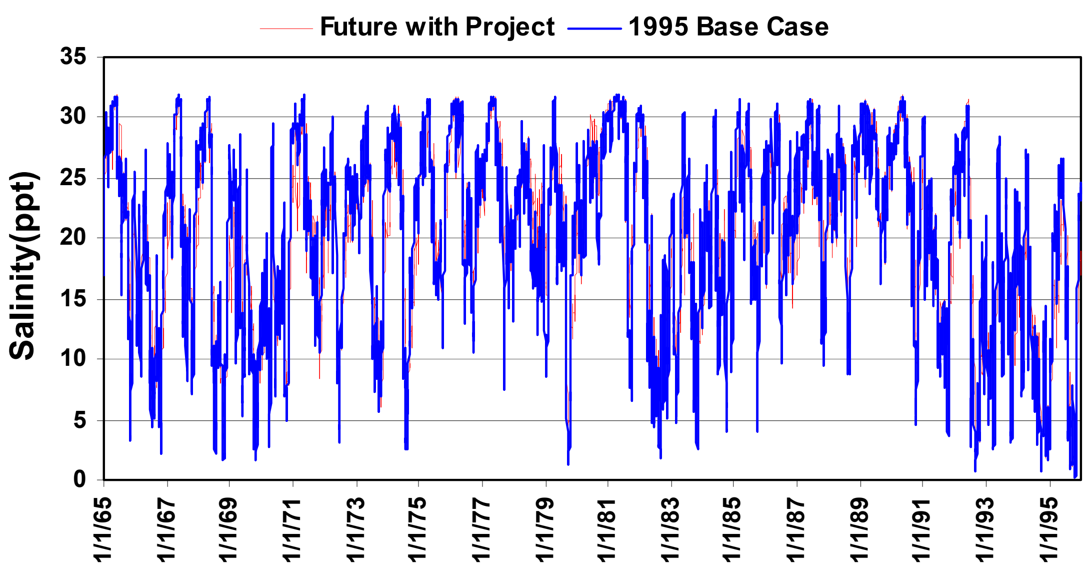

Figure H-13. Future with Project versus Present (1995 Base Case) Conditions Salinity at US 1 (Roosevelt) Bridge

REFERENCES

Hu, G. 1999. Two-dimensional Hydrodynamic Model of St. Lucie Estuary. In: *Environmental Engineering 1999*, *Proceedings of the ASCE-CSCE National Conference on Environmental Engineering*, American Society of Civil Engineers, pp 434-443.

Hu, G., and Unsell, D. 1998. Tidal Circulation in the Southern Indian River Lagoon. In: *Water Resources Engineering'98*, *Proceedings of the International Water Resources Engineering Conference* 1:844-849, American Society of Civil Engineers.